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Thermal Tuning of a Microwave Water-Based Metasurface

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I. INTRODUCTION

Fluidic metamaterials (MMs) have received increasing interest with their tunability and promising applications such as material sensing, bio-detection, imaging etc. [1]. With its relatively high permittivity [2, 3], water introduces many tuning-variables into MMs due to its temperature dependent parameters. It has been shown that water-based MMs can be tuned thermally, chemically and by reshaping/deforming of as well as partially filling their containers [4, 5]. Water-based metasurface (MS) absorbers are investigated heavily, where the latest MS had a 90% absorption from 20 – 40 GHz [6].

In [7], we studied a MS with a square lattice of ‘rod-like’ water inclusions in a foam material (the unit cell is shown in Fig. 1). The MS was capable of switching between reflecting and transmitting the incident power through 90° rotation of the MS. Furthermore, stacking several of these MSs effectively increased the switching efficiency.

Presently, we continue the study of the same MS as in [7] by investigating its thermal tunability in the temperature range from 0 °C to 100 °C. The thermal volumetric expansion of water has been neglected, since a temperature change from 20 °C to 100 °C only expand the volume with approximately 4% (density from 1 g/cm³ to 0.96 g/cm³). For a sphere, this corresponds to the radius increases with around 1% with similar red-shift of the spectrum.

II. CONFIGURATION AND RESULTS

A single unit cell of the MS is presented in Fig. 1 with its two cross sections. It consists of a water inclusion in a Rohacell 51 HF host. The water inclusion has the shape of a rounded rectangular cuboid and the geometrical parameters are shown in the figure. Their values are: $a = d = 50$ mm, $r = 10.7$ mm, and $h = d_e = 45$ mm. The angle ϕ describes the rotation of the unit cell (or MS). The complex relative permittivity of water was taken from [2] and the relative permittivity of Rohacell 51 HF was measured in-house to be 1.075. The MS was implemented into Comsol Multiphysics used for the numerical calculations.

The electromagnetic response of the MS to a y -polarized plane wave at normal incidence travelling in the positive z -direction is investigated. The MS is characterized by the transmitted (transmittance) and reflected (reflectance) in-

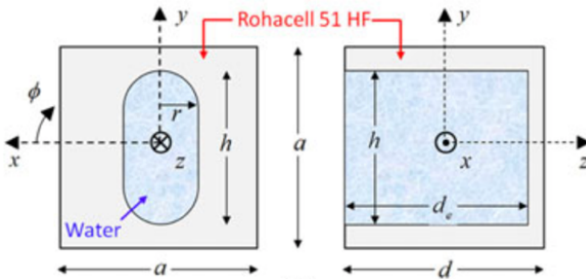


Fig. 1. Two cross sections of a single unit cell of MS.

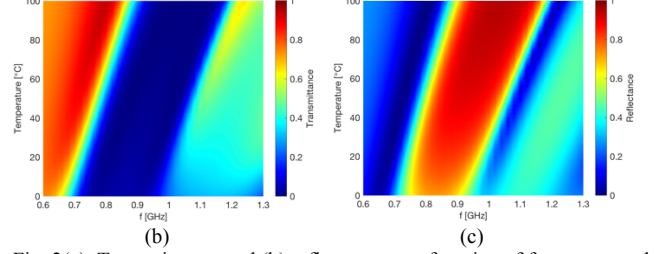


Fig. 2(a). Transmittance and (b) reflectance as a function of frequency and temperature for $\phi = 0^\circ$. The colors show the magnitude of the transmittance and reflectance.

cident power. In Fig. 2, the transmittance (Fig. 2(a)) and reflectance (Fig. 2(b)) are shown as functions of frequency and temperature depicting the thermal tunability of the MS for rotation angle $\phi = 0^\circ$. Increasing the temperature from 20 °C to 100 °C blue-shifts the spectrum by around 200 MHz in the investigated range of frequencies (0.6 – 1.3 GHz). This is not unexpected since the relative permittivity of water decreases from approximately 80 to 56 decreasing the electrical size of the inclusions. The imaginary part of the permittivity, which is related to the losses, decreases from 4.5 to 0.7 giving the higher transmittance at higher temperatures in the lower and upper part of the spectrum. In the middle part, the transmittance decreases, while the reflectance increases, because the magnetic and electric resonances are less affected by the losses [7]. A similar study has been done for the rotation angle $\phi = 90^\circ$ showing similar behaviour with temperature variation.

III. CONCLUSIONS

The thermal tunability of a water-based MS was investigated showing a frequency shift of around 200 MHz of the spectrum. The proposed water-based MS can be a cost-effective and bio-friendly alternative for microwave applications.

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